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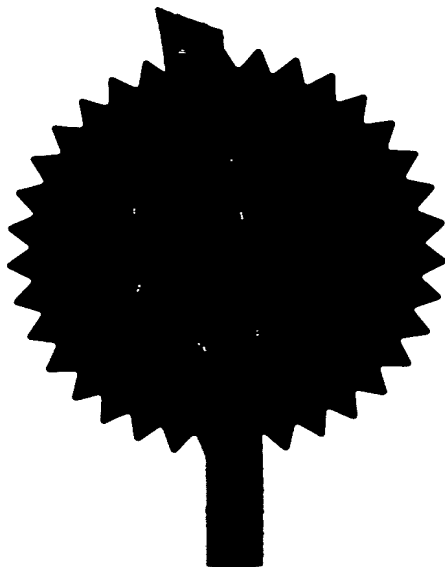
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Liquid Crystal Device

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PATENT APPLICATION
LIQUID CRYSTAL DEVICE

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Slippery Surfaces cases:

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1 (P2618) general case genslip.1 - cover all the following file on same day

2 (P2619) bistable case - bislip1.doc was pat4 etc involves HP

3. (P2620) twisted nematic tnslip1.doc improves TN devices was pat5 etc

4 (P2621) ferro electric - feslip1.doc improves FELCDs

25

LIQUID CRYSTAL DEVICE

This invention relates to the alignment and switching of nematic liquid crystal devices.

5

Liquid crystal devices typically comprise of a thin layer of a liquid crystal material contained between cell walls. Optically transparent electrode structures on the walls allow an electric field to be applied across the layer causing a re-ordering of the liquid crystal molecules.

10

There are three known types of liquid crystal material nematic, cholesteric and smectic each having different molecular ordering. The present invention concerns devices using nematic and long pitch cholesteric materials.

15

In order to provide displays with a large number of addressable elements it is common to make the electrodes as a series of row electrodes on one wall and a series of column electrodes on the other cell wall. These form e.g. an x,y matrix of addressable elements or pixels and for twisted nematic types of device are commonly addressed using rms addressing methods.

20

Twisted nematic (TN) and phase change devices are switched to an ON state by application of a suitable voltage and allowed to switch to an OFF state when the applied voltage falls below a lower voltage level, i.e. these devices are monostable. For a twisted nematic type of device (90° or 270° twist as in US 4,596,446) the number of
25 elements that can be rms addressed is limited by the steepness of a device transmission verses voltage curve (as described by Alt and Pleschko in IEEE Trans ED vol ED 21, (1974) P.146 - 155). One way of improving the number of pixels is to incorporate thin film transistors adjacent to each pixel; such displays are termed active matrix displays.

An advantage of nematic types of devices is the relatively low voltage requirements. They are also mechanically stable and have a wide temperature operating range. This allows construction of small and portable battery powered displays. An alternative
5 twisted nematic device is one which is switched from a non-twisted state at zero volts to a twisted state at a higher voltage as described in GB 9607854.8 which will be referred to in this patent as a VCT device.

One problem with the twisted nematic device is that the contrast ratio of a normally
10 white display remains at a low value until the voltage is increased to a value considerably higher than the threshold voltage. This is due to the nematic material close to the cell walls which does not fully reorient in the applied field due to the strong zenithal anchoring imposed by the surface alignment layer. This lack of surface reorientation also leads to higher voltage operation in the VCT device.

15 The terms azimuth or azimuthal is used herein to define the molecular (or director \underline{n}) alignment angle movement or energy in the plane of the wall surface. The terms zenith or zenithal is used herein to define the molecular alignment angle movement or energy in a plane normal to the wall surface

20 According to this invention, the contrast ratio of a twisted nematic device can be improved by using an additional surface treatment which reduces the zenithal anchoring energy of the surface and thereby allows field-induced reorientation of the near-surface nematic layers. Such a treatment also has the added advantage of leading
25 to a lowering of the threshold voltage. Lower voltage operation is preferable for both passive matrix and active matrix twisted nematic devices as it allows a display to operate with a lower power consumption.

According to this invention a twisted nematic liquid crystal device capable of being switched from a twisted stated to a non twisted state comprises:

- 5 two cell walls enclosing a layer of nematic liquid crystal material:

electrode structures on both walls for applying an electric field across the liquid crystal layer:

- 10 a surface alignment on both cell walls providing alignment direction to liquid crystal molecules and arranged so that a twisted nematic structure is formed across the liquid crystal layer at either zero volts or at a higher voltage:

- means for distinguishing between the two different optical states of the liquid crystal
15 material;

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- means for reducing zenithal anchoring energy in the surface alignment on one or both
20 cell walls.

Additionally the azimuthal anchoring energy may also be reduced.

The means for reducing azimuthal anchoring energy and zenithal anchoring energy may be an oligomer containing esters, thiol, and/or acrylate monomers either spread on the surface or added to the liquid crystal material. e.g. the materials N65 and
5 MXM035.

The oligomers may migrate preferentially to the surface in order to minimise the surface free energy. This may dilute the amount of liquid crystal at the surface leading to an effective reduction in the order parameter, S which is defined by (P. G.
10 deGennes, The Physics of Liquid Crystals, Clarendon Press, Oxford 1974):

$$S = \frac{1}{2} \langle (3 \cos^2 \theta - 1) \rangle$$

The order parameter is an indication of how well molecules align in a cell. Additionally the phase of the liquid crystal material at the surface may be changed by
15 the oligomers, eg from nematic or long pitch cholesteric to isotropic.

The treatment may be used in conjunction with a surface which induces monostable pretilted nematic alignment.

20 The alignment layer may be a rubbed polymer surface as described in S. Ishihara et al, Liq. Cryst., vol.4, no. 6, p.669-675 (1989) or an obliquely evaporated inorganic material as described in W. Urbach, M. Boix and E. Guyon, Appl. Phys. Lett., vol. 25, no. 9, 479 (1974) or a polymer surface where in-plane anisotropy is achieved by illumination with polarised light such as M. Schadt et al. Jpn. J. Appl. Phys., v. 31,
25 no.7, p. 2155 (1992).

Alternatively the alignment layer may be a surface monograting with an asymmetric groove profile as described in G. P. Bryan-Brown and M. J. Towler. "Liquid crystal device alignment". GB 2.286.466A (GB9402492.4).

The alignment directions on the two surface may be substantially perpendicular.

The nematic liquid crystal may contain a small amount ($<5\%$) of a chiral dopant material e.g., R1011, CB15 Merck.

5

The cell walls may be substantially rigid e.g. glass material, or flexible e.g. polyolefin.

The electrodes may be formed as a series of row and column electrodes arranged and an x,y matrix of addressable elements or display pixels. Typically the electrodes are

10 200 μ m wide spaced 20 μ m apart.

Alternatively, the electrodes may be arranged in other display formats e.g. r- θ matrix or 7 or 8 bar displays.

15 The invention will now be described, by way of example only with reference to the accompanying drawings of which:

Figure 1 is a plan view of a matrix multiplexed addressed liquid crystal display:

20 Figure 2 is the cross section of the display of figure 1;

Figure 3 shows the theoretical surface director tilt versus voltage for values of surface extrapolation lengths L.

25 Figure 4 shows the theoretical midlayer director tilt versus voltage for values of L

Figure 5 shows the configuration for photolithographic exposure leading to the formation of an asymmetric monograting.

Figure 6 shows the transmission versus voltage data for two cells, one of which (dotted line) has been treated with an additive (Norland 65) to give weak anchoring. Gratings have been used on both surfaces for alignment.

- 5 Figure 7 shows the optical contrast ratio versus voltage data for two cells, one of which (dotted line) has been treated with an additive to give weak anchoring.

Figure 8 shows the transmission versus voltage data for two cells, one of which (dotted line) has been treated with an additive (MXM035) to give weak anchoring. Gratings have been used on both surfaces for alignment. Cell gaps are $2.05\mu\text{m}$

10

Figure 9 shows the transmission versus voltage data for two cells, one of which (dotted line) has been treated with an additive (MXM035) to give weak anchoring. Gratings have been used on both surfaces for alignment. Cell gaps are $4.6\mu\text{m}$.

15

Figure 10 shows the transmission versus voltage data for two cells, one of which (dotted line) has been treated with an additive (MXM035) to give weak anchoring. Rubbed polymer layers have been used on both surfaces for alignment. Cell gaps are $4.6\mu\text{m}$.

20

Figure 11 shows the transmission versus voltage data for two VCT cells, one of which (dotted line) has been treated with an additive (MXM035) to give weak anchoring energy.

- 25 The display in figures 1, 2 comprises a liquid crystal cell 1 formed by a layer 2 of nematic or long pitch cholesteric liquid crystal material contained between glass walls 3, 4. A spacer ring 5 maintains the walls typically $2\text{-}10\mu\text{m}$ apart. Additionally numerous beads of the same dimensions may be dispersed within the liquid crystal to maintain an accurate wall spacing. Strip like row electrodes 6 e.g. of SnO_2 or ITO are
- 30 formed on one wall 3 and similar column electrodes 7 are formed on the other wall 4. With m-row and n-column electrodes this forms an $m \times n$ matrix of addressable

elements or pixels. Each pixel is formed by the intersection of a row and column electrode. A row driver 8 supplies voltage to each row electrode 6. Similarly a column driver 9 supplies voltages to each column electrode 7. Control of applied voltages is from a control logic 10 which receives power from a voltage source 11 and timing
5 from a clock 12.

Either side of the cell 1 are polarisers 13, 13' arranged with their polarisation axis substantially crossed with respect to one another. An additional optical compensator such as a stretched plastic film may also be added between the liquid crystal cell and
10 one of the polarisers. A partly reflecting mirror 16 may be arranged behind the cell 1 together with a light source 15. These allow the display to be seen in reflection and lit from behind in dull ambient lighting. For a transmission device, the mirror may be omitted.

15 Prior to assembly, the cell walls 3, 4 are treated with alignment treatments to provide a monostable pretilted alignment. Finally the cell is filled with a nematic material which may be e.g. E7, ZLI2293 or MLC 6608 (Merck), and may include a chiral additive such as CB15 or R1011 (Merck).

20 These materials may contain the treatment or a precursor of the treatment which leads to a lowering of the anchoring energy.

In general anchoring of a nematic liquid crystal on a surface can be described by three macroscopic parameters, pretilt, zenithal anchoring energy and azimuthal anchoring energy. Consider a surface in the x-y plane, parallel to the cell walls. The pretilt (θ_p) is defined as the preferred angle of inclination of the nematic director with respect to the x-y plane. To change the tilt of the surface director from θ_p to an arbitrary tilt θ , an energy per unit area of W must be supplied to the system where [A. Rapini and M. Papoular, J. Phys. (Paris), 36, C-1, 194 (1975)]:

$$W = W_\theta \sin^2 (\theta - \theta_p) \quad (1)$$

W_θ is the zenithal anchoring energy and represents the energy required in order change the tilt of the surface director by 90° . If the director has a preferred in-plane orientation, say along the x axis, then an energy must be supplied to the system to change this orientation. The energy is now given by

$$W = W_\phi \sin^2 \phi \quad (2)$$

where ϕ is the change in the in-plane orientation and W_ϕ is the azimuthal anchoring energy.

Pretilt and zenithal anchoring can be achieved from most solid surfaces while azimuthal anchoring usually requires some extra treatment in order to obtain a preferred in-plane direction such as an anisotropic polymer, obliquely evaporated film or a surface grating. For most surfaces W_θ and W_ϕ are large and so reorientation of the director at the surface only occurs at high voltages.

The effect of the weak zenithal anchoring on a twisted nematic device is discussed below.

The improvement in operation of a 90° twisted nematic cell with weak surface anchoring was first analysed theoretically. The static configuration of the cell was calculated by minimising the total free energy which is dictated by the Euler-Lagrange equation in the bulk and by equations (1) and (2) at the surfaces. The zenithal anchoring energy W_θ was then relaxed from its usual large value and the effect on the static configuration was calculated. Figure 3 shows several curves calculated for different surface extrapolation lengths, L where $L = k_{11} / W_\theta \cdot d$. The parameters common to all the curves are ;

$k_{22}/k_{11} = 0.6$; $k_{33}/k_{11} = 1.5$; $\epsilon_{\text{para}} = 14.0$; $\epsilon_{\text{per}} = 4.0$; Cell twist = 90°; Surface pretilt = 5°

The reduced voltage is defined as the voltage which has been normalised by the Fredericksz threshold voltage ($= \sqrt{k_{11} / \epsilon_o \Delta \epsilon}$). Figure 3 shows the surface tilt angle as a function of applied voltage. For infinite zenithal anchoring energy ($L=0.0$) the tilt remains fixed at the zero volt pretilt value. However for finite anchoring ($L>0$) all the curves show that the surface director is reoriented by the applied field and shows an increasing tilt angle with voltage. It is expected that this voltage induced tilt will lead to a better contrast ratio in a typical normally-white twisted nematic device.

Figure 4 has been calculated with the same parameters as figure 3 but now shows the voltage dependent tilt in the middle of the nematic layer. This tilt angle is the dominant parameter in dictating the optical transmission of the twisted nematic device. Therefore it is clear to see that a surface offering a finite L will lead to a lower voltage, steeper electrooptic response.

Therefore the above modelling has shown that a surface treatment which lowers W_θ will lead to a twisted nematic device which has a lower voltage threshold, a steeper electrooptic response and a higher contrast at a given voltage

Example 1

An example of a weak anchoring treatment applied to a twisted nematic is now given. The pretilted alignment surface used in this example was an asymmetric monograting as described in GB 9402492.4; GB-A-2.296.466; WO-95/22078.

5

The treatment consists of adding a small (1-10%) amount of a UV curing adhesive material to the nematic prior to cell filling. Examples of suitable materials include N65, N63, N60 or N123 (All manufactured by Norland Products Incorporated, North Brunswick, NJ, USA). In this particular example, one of these materials (N65) is used
10 as an additive to the nematic E7 (Merck). This material contains a mixture of esters and acrylate monomers which polymerise under UV radiation.

Before using the N65 additive in a twisted nematic device a set of experiments were carried out in order to show the effect of the N65 treatment on the zenithal anchoring
15 energy, W_θ . This quantity can be calculated by measuring the saturation voltage, V_s . That is, the voltage at which the director tilt in the cell is perpendicular to the surface throughout the thickness of the cell. This can be measured in cells where the surfaces have no preferred alignment direction. In this case flat surfaces of hardbaked photoresist were used (Shipley 1805). This material was spin coated on ITO coated
20 glass to form a $0.55\mu\text{m}$ thick layer. Baking at 160°C for 45 minutes ensured full insolubility in the liquid crystal. When filled with N65/E7 mixtures, these cells show a random Schlieren texture. The saturation voltage was measured by observing when the transmitted intensity of the Schlieren texture falls to zero when viewed between crossed polarisers. W_θ is then given by

25

$$W_\theta \approx \frac{3.85 \sqrt{\epsilon_o \Delta \epsilon k_{11}} \cdot V_s}{d} \quad (4)$$

where d is the liquid crystal thickness, k_{11} is the liquid crystal splay elastic constant and $\Delta \epsilon$ is the liquid crystal permittivity anisotropy.

Results are shown in table 1. The pure E7 cell failed to show a black state before cell breakdown and so only a lower limit on W_{θ} can be given. In the cases of the E7 containing N65, the curing was performed in a fused silica cell for 10 minutes prior to transferring the mixture to a separate measurement cell. The exposure was carried out using an unfiltered mercury lamp with an optical output of 2.0 mW/cm^2 at a raised temperature of 65°C .

Cell mixture	$W_{\theta} (\text{N m}^{-1})$
Pure E7	$>5 \times 10^{-2}$
2% N65 in E7	6.3×10^{-3}

Table 1

10 Surface zenithal anchoring energies modified by the presence of N65.

The above results clearly show that the N65 has reduced the value of W_{θ} in a cell with flat surfaces. The next step is to study the effect of this additive on the operation of a twisted nematic device.

15

Such a twisted nematic device may employ asymmetric monogratings to induce pretilted alignment and be fabricated in the following way as shown in Figure 5: Shipley 1805 photoresist 20 was spin coated at 3000 rpm onto ITO coated glass 21 for 30 seconds. Next the photoresist layer 20 was baked at 90°C for 30 minutes to remove the solvent. Exposure of the photoresist through a mask 22 was carried out using off axis hard contact photolithography. The mask 22 consisted of a chrome on glass pattern with a pitch of $1 \mu\text{m}$ ($0.5 \mu\text{m}$ gaps and $0.5 \mu\text{m}$ chrome strips). The exposure time was set to 540 seconds with an incident power of 0.15 mW/cm^2 from a mercury lamp. Development was then carried out in Shipley MF319 for 10 s followed by a water
25 rinse. Samples were finally baked at 160°C for 45 minutes after first receiving a deep UV exposure to preharden the photoresist (3.36 J/cm^2 at 254 nm).

The above process resulted in a surface monograting with a $1\mu\text{m}$ pitch and a $0.5\mu\text{m}$ peak to trough groove depth. The profile is asymmetric (approximately sawtooth in form) which leads to a pretilted alignment if the nematic is under the influence of a bulk twist torque (see GB-A-2,296,466: WO-95/22078). These surfaces were constructed into cells in which the groove direction on one surface was orthogonal to the groove direction on the other. The cell gap was set to $2.05\mu\text{m}$ which corresponds to the first Gooch and Tarry minimum when used with E7 (J. Phys. D. Appl. Phys. vol. 8, p. 1575 (1975)). Filling was then carried out using E7 in the isotropic phase (65°C) followed by slow cooling to room temperature.

The electrooptic response of cells containing different N65/E7 mixtures was then recorded by placing the twisted nematic cell between crossed polarisers which were oriented parallel to the adjacent grating alignment directions. Transmission was measured using a photodiode with a photo-optic response during the application of a 1kHz sinusoidal drive waveform. Figure 6 shows the transmission versus rms voltage for two cells one of which was treated to give weak anchoring. The weak anchoring treatment consisted of adding 2% N65 to E7 and curing for 10 minutes in a pre-cell before transferring the material to the test cell. The data clearly shows that the weak anchoring treatment has lowered the operating voltage. A transmission of 50% of the zero volt value is reached at a voltage of 1.83 V for the weak anchored surface and 2.13 V for the strong anchored surface. The power consumption of a display can be considered in the most simple case as the power required to charge and discharge a capacitor which is proportional to V^2 . Therefore the weak anchored surface is expected to allow a power saving of roughly 35%.

The second improvement of the weak anchored cell is the improved optical contrast ratio as shown in figure 7. At 5 V the weak anchored cell has a contrast ratio of 126 while the strong anchored cell has a contrast ratio of 49. At 8 V the difference is even larger (410 and 74 respectively). Therefore if a particular application demands a certain contrast ratio then it can be reached at a much lower voltage with a weak

anchored surface. The weak anchoring has also lead to a slight increase in the steepness of the electrooptic response. For the weak anchored surface $V_{90} - V_{50}$ is 0.454 V while for the strong surface this quantity is 0.510 V: V_{90} and V_{50} being the voltage at transmissions of 90% and 50% of the zero voltage transmission value
5 respectively.

In summary the above experimental results have shown qualitative agreement with the theoretical analysis by demonstrating that a surface which has been treated to give a lower W_{θ} can improve a twisted nematic device. The improvements include a lower
10 voltage threshold, a steeper electro optic response and a higher optical contrast.

Example 2

In this example MXM035 (Merck) was used as the weak anchoring treatment. The
15 alignment surfaces were asymmetric monogratings as described in example 1.

The MXM035 consists of two parts which were mixed in equal quantities. This mixture was then added to E7 nematic to give a 4% solution which was cured in a fused silica cell (as described in example 1) before transferring to a test cell. A
20 measurement of W_{θ} for the 4% solution revealed a value of $3.85 \times 10^{-4} \text{ J/m}^2$. This is 16 times smaller than the value of measured for N65 (in example 1). Therefore the MXM 035 treatment is expected to have a larger effect on the operating behaviour of a TN device.

25 Cells were constructed using asymmetric monogratings as alignment surfaces. The groove direction on one surface was orthogonal to that on the other to ensure a twisted configuration with a liquid crystal twist of roughly 90° . The cell gap was set to $2.05 \mu\text{m}$ (the first Gooch and Tarry minimum). Figure 8 shows the transmission versus rms voltage for two cells. one of which was treated with 4% MXM035 to give weak
30 anchoring. In this case the weak anchoring treatment has lead to a very large decrease

in operating voltage. A transmission of 50% of the zero volt value is reached at a voltage of 0.8 V for the weak anchored surface compared to 1.93 V for the strong anchored surface. Hence the weak anchored TN is expected to use only 17% of the operating power of a conventional TN.

5

Weak anchoring treatments can also lead to improvements in performance when the cell gap is larger. To demonstrate this, data was taken from two more TN cells which had been constructed with a cell gap of $4.6\mu\text{m}$ which corresponds to the second Gooch and Tarry minimum for E7. One of these was filled with pure E7 while the other was
 10 filled with 4% MXM035 in E7 which had been precured as described above. Figure 9 shows the electrooptic response for these two cells. Once again the weak anchored cell shows a response at a much lower voltage. The 50% transmission occurs at 1.07 V for the weak anchored TN compared to 2.16 V for the conventional TN. The weak anchoring treatments are expected to change the dynamic response of the TN and so
 15 optical response times were measured for these cells for switching between 0 V and 4V as shown in table 2. It can be seen that the addition of MXM035 has lead to a decrease in switch-on time (τ_{on}) and an increase in switch-off time (τ_{off}). This behaviour is consistent with weak surface anchoring.

Cell Mixture	τ_{on} (ms)	τ_{off} (ms)
E7	6.8	15.5
E7 + 4%MXM035	2.5	24.0

20

Table 2

0-4 V optical switching times for second minimum TN cells with strong or weak anchoring. .

25

Example 3

Weak anchoring treatments can also be used in conjunction with other surface alignments to improve TN performance. In this example the MXM035 treatment is
5 used in conjunction with a rubbed polymer alignment.

Rubbed alignment surfaces were prepared by spin coating a layer of probomide 32 (Ciba Geigy) onto ITO coated glass and baking the substrates at 300°C. The surfaces were then rubbed in one direction by a nylon cloth attached to a rotating roller. Finally
10 cells were constructed in which the rubbing direction on one surface was orthogonal to that on the other. The cell gap was set to 4.6µm using monodispersed spacer beads in the edge seal. Figure 10 shows a comparison of electrooptic responses recorded from two TN cells, one filled with E7 and the other filled with E7+ 4% MXM035. Once again the addition of the weak anchoring treatment has lead to a reduction in operating
15 voltage.

Example 4

One particular type of twisted nematic device is the VCT device which switches from
20 a substantially non-twisted state to a twisted state when a voltage is applied. In this example the operation of the VCT device is improved by the addition of a weak anchoring treatment. The surface alignment in this example was provided by asymmetric grating surfaces as described in example 1.

25 The weak anchoring treatment was MXM035 mixed from 10 % of part A and 90% of part B. 4% of this mixture was added to nematic MLC 6608 which has a negative dielectric anisotropy. The MXM035 was then cured by placing the MXM035/MLC6608 mixture in a glass cell and exposing to UV radiation (10 minutes at 2.0mW/cm² while at a temperature of 65°C). After curing the mixture was used to
30 fill a VCT test cell.

The VCT cells were constructed so that the grating grooves on one surface were orthogonal to those on the other. Prior to construction the grating on one surface was treated with a chrome complex surfactant in order to induce a homeotropic boundary condition (molecules perpendicular to the wall surface). The grating on the other surface was left untreated in order to induce a planar boundary condition. The cell gap was set to 5.3 μm using spacer beads in the edge seal. Figure 11 shows the electrooptic response of two VCT devices, one of which contains the weak anchoring treatment. The VCT containing pure MLC6608 exhibits 50% transmission at a voltage of 2.91 V while the VCT containing 4% MXM035 in MLC 6608 exhibits 50% transmission at a voltage of 1.52 V: Therefore the weak anchoring treatment has lead to a dramatic decrease in operating voltage.

The dynamic response times of the VCT were measured for these cells for switching between 0 V and 5V as shown in table 3. It can be seen that the addition of MXM035 has lead to a decrease in switch-on time (τ_{on}) and an increase in switch-off time (τ_{off}).

Cell Mixture	τ_{on} (ms)	τ_{off} (ms)
MSc 6608	86	60
MSC 6608 + 4%MXM035	60	112

Table 3

0-5 V optical switching times for VCT cells with strong or weak anchoring.

The above examples show that the addition of oligomeric materials (Norland 65. MXM035) into cells with either grating surfaces or rubbed polymer surfaces will lead to a reduction in the operating voltage of a twisted nematic device.

The monomer materials used may include the following, which are given only by way of example:

methyl acrylate	propane-1,3-diol diacrylate
ethyl acrylate	butane-1,4-diol diacrylate
propyl acrylate	pentane-1,5-diol diacrylate
butyl acrylate	hexane-1,6-diol diacrylate
pentyl acrylate	heptane-1,7-diol diacrylate
2-methylbutyl acrylate	octane-1,8-diol diacrylate
hexyl acrylate	nonane-1,9-diol diacrylate
heptyl acrylate	decane-1,10-diol diacrylate
octyl acrylate	glycerol triacrylate
nonyl acrylate	trimethylolpropane triacrylate
decyl acrylate	pentaerythritol triacrylate
ethyl hexyl acrylate	pentaerythritol tetraacrylate
methyl methacrylate	di-pentaerythritol hexaacrylate
ethyl methacrylate	ethylene glycol dimethacrylate
propyl methacrylate	1,2-propylene glycol dimethacrylate
butyl methacrylate	propane-1,3-diol dimethacrylate
pentyl methacrylate	butane-1,4-diol dimethacrylate
2-methylbutyl methacrylate	pentane-1,5-diol dimethacrylate
hexyl methacrylate	hexane-1,6-diol dimethacrylate
heptyl methacrylate	heptane-1,7-diol dimethacrylate
octyl methacrylate	octane-1,8-diol dimethacrylate
nonyl methacrylate	nonane-1,9-diol dimethacrylate
decyl methacrylate	decane-1,10-diol dimethacrylate
ethyl hexyl methacrylate	glycerol trimethacrylate
styrene	trimethylolpropane trimethacrylate
ethylene glycol diacrylate	pentaerythritol trimethacrylate
1,2-propylene glycol diacrylate	pentaerythritol tetramethacrylate
	di-pentaerythritol hexamethacrylate

A further class of polymers includes di-thiol/diene polymers prepared by the copolymerisation of difunctional alkenes with difunctional thiols under free radical conditions. Monofunctional and/or polyfunctional alkenes and/or thiols may be incorporated in order to modify the properties of the polymer, for example to reduce the molecular weight of the polymer or to introduce a controlled degree of crosslinking in the polymer. The following materials given by way of example only may be included in polymers suitable for the subject of the invention:

methyl acrylate	styrene
ethyl acrylate	ethylene glycol diacrylate
propyl acrylate	1,2-propylene glycol diacrylate
butyl acrylate	propane-1,3-diol diacrylate
pentyl acrylate	butane-1,4-diol diacrylate
2-methylbutyl acrylate	pentane-1,5-diol diacrylate
hexyl acrylate	hexane-1,6-diol diacrylate
heptyl acrylate	heptane-1,7-diol diacrylate
octyl acrylate	octane-1,8-diol diacrylate
nonyl acrylate	nonane-1,9-diol diacrylate
decyl acrylate	decane-1,10-diol diacrylate
ethyl hexyl acrylate	glycerol triacrylate
methyl methacrylate	trimethylolpropane triacrylate
ethyl methacrylate	pentaerythritol triacrylate
propyl methacrylate	pentaerythritol tetraacrylate
butyl methacrylate	di-pentaerythritol hexaacrylate
pentyl methacrylate	ethylene glycol dimethacrylate
2-methylbutyl methacrylate	1,2-propylene glycol dimethacrylate
hexyl methacrylate	propane-1,3-diol dimethacrylate
heptyl methacrylate	butane-1,4-diol dimethacrylate
octyl methacrylate	pentane-1,5-diol dimethacrylate
nonyl methacrylate	hexane-1,6-diol dimethacrylate
decyl methacrylate	heptane-1,7-diol dimethacrylate

ethyl hexyl methacrylate
ethylene glycol divinyl ether
1,2-propylene glycol divinyl ether
propane-1,3-diol divinyl ether
butane-1,4-diol divinyl ether
pentane-1,5-diol divinyl ether
hexane-1,6-diol divinyl ether
heptane-1,7-diol divinyl ether
octane-1,8-diol divinyl ether
nonane-1,9-diol divinyl ether
decane-1,10-diol divinyl ether
glycerol trivinyl ether
trimethylolpropane trivinyl ether
divinyl benzene
butane-1,3-diene
pentane-1,4-diene
hexane-1,5-diene
heptane-1,7-diene
octane-1,7-diene
nonane-1,8-diene
decane-1,9-diene
ethylene glycol dithioglycollate
1,2-propylene glycol dithioglycollate
propane-1,3-diol dithioglycollate
butane-1,4-diol dithioglycollate
pentane-1,5-diol dithioglycollate
hexane-1,6-diol dithioglycollate
heptane-1,7-diol dithioglycollate
octane-1,8-diol dithioglycollate
nonane-1,9-diol dithioglycollate
decane-1,10-diol dithioglycollate

octane-1,8-diol dimethacrylate
nonane-1,9-diol dimethacrylate
decane-1,10-diol dimethacrylate
glycerol trimethacrylate
trimethylolpropane trimethacrylate
pentaerythritol trimethacrylate
pentaerythritol tetramethacrylate
di-pentaerythritol hexamethacrylate
ethylene glycol diallyl ether
1,2-propylene glycol diallyl ether
propane-1,3-diol diallyl ether
butane-1,4-diol diallyl ether
pentane-1,5-diol diallyl ether
hexane-1,6-diol diallyl ether
heptane-1,7-diol diallyl ether
octane-1,8-diol diallyl ether
nonane-1,9-diol diallyl ether
decane-1,10-diol diallyl ether
glycerol triallyl ether
trimethylolpropane triallyl ether
di-allyl malonate
di-allyl succinate
di-allyl glutanate
di-allyl hexane-1,6-dicarboxylate
di-allyl heptane-1,7- dicarboxylate
di-allyl octane-1,8- dicarboxylate
di-allyl nonane-1,9- dicarboxylate
di-allyl decane-1,10- dicarboxylate
di-allyl undecane-1,11- dicarboxylate
di-allyl dodecane-1,12- dicarboxylate
di-allyl phthalate

glycerol trithioglycollate	butane-1,4-diol di-3-mercaptopropionate
trimethylolpropane trithioglycollate	pentane-1,5-diol di-3-mercaptopropionate
pentaerythritol trithioglycollate	hexane-1,6-diol di-3-mercaptopropionate
pentaerythritol tetrathioglycollate	heptane-1,7-diol di-3-mercaptopropionate
di-pentaerythritol hexathioglycollate	octane-1,8-diol di-3-mercaptopropionate
4,4'-thiobisbenzenethiol	nonane-1,9-diol di-3-mercaptopropionate
di-allyl iso-phthalate	decane-1,10-diol di-3-mercaptopropionate
di-allyl terephthalate	glycerol tri-3-mercaptopropionate
ethane dithiol	trimethylolpropane tri-3-mercaptopropionate
propane dithiol	pentaerythritol tri-3-mercaptopropionate
butane dithiol	pentaerythritol tetra-3-mercaptopropionate
pentane dithiol	di-pentaerythritol hexa-3-
	mercaptopropionate
hexane dithiol	Also commercial polymers from Norland
	and Merck eg Norland 65, Norland 63 and
	Merck MXM035
heptane dithiol	
octane dithiol	
nonane dithiol	
decane dithiol	
undecane dithiol	
dodecane dithiol	
ethylene glycol di-3-	
mercaptopropionate	
1,2-propylene glycol di-3-	
mercaptopropionate	
propane-1,3-diol di-3-	
mercaptopropionate	

CLAIMS

1. A twisted nematic liquid crystal device capable of being switched from a twisted
stated to a non twisted state comprising;

5

two cell walls enclosing a layer of nematic liquid crystal material:

electrode structures on both walls for applying an electric field across the liquid crystal
layer:

10

a surface alignment on both cell walls providing alignment direction to liquid crystal
molecules and arranged so that a twisted nematic structure is formed across the liquid
crystal layer:

15 means for distinguishing between the two different optical states of the liquid crystal
material;

CHARACTERISED BY

20 means for reducing zenithal anchoring energy in the surface alignment on one or both
cell walls.

2. The device of claim 1 wherein the means for reducing zenithal anchoring energy is
an oligomer which is coated onto the inner surface of one or both cell walls either
25 spread on the surface or added to the liquid crystal material.

3. The device of claim 1 wherein the means for reducing and zenithal anchoring
energy is an oligomer incorporated in the liquid crystal material.

30 4. The device of claim 1 wherein the means for reducing zenithal anchoring energy is
N65, or MMXM035.

5. The device of claim 1 wherein the means for reducing zenithal anchoring energy is a material containing esters, thiols, and/or acrylate monomers.
6. The device of claim 1 wherein the means for reducing zenithal anchoring energy
5 reduces the liquid crystal material order parameter at or adjacent the cell walls.
7. The device of claim 1 wherein the means for reducing zenithal anchoring energy changes the phase of the liquid crystal material at or adjacent the cell walls.
- 10 8. The device of claim 1 including means for reducing azimuthal anchoring energy.
9. The device of claim 1 wherein the surface alignment provides a pretilted nematic alignment on both cell walls.
- 15 10. The device of claim 1 wherein the surface alignment is provided by a rubbed polymer, a photo-ordered polymer or an obliquely evaporated inorganic material.
11. The device of claim 1 wherein the surface alignment layer is a surface monograting with an asymmetric groove profile.
- 20 12. The device of claim 1 wherein the alignment directions on the two surface are substantially perpendicular.
13. The device of claim 1 wherein the liquid crystal director twists by about 90°
25 throughout the thickness of the cell.
14. The device of claim 1 wherein the liquid crystal director twists is greater than 180° and less than 360° .
- 30 15. The device of claim 1 wherein the nematic liquid crystal material contains a small amount ($<5\%$) of a chiral dopant material.

Abstract

A twisted nematic liquid crystal device has a lowered switching voltage with an
5 enhanced contrast ratio between ON and OFF states. The improvement is provided by
reducing the zenithal anchoring energy of liquid crystal molecules at a wall;
additionally the azimuthal anchoring energy may also be reduced. The device
comprises a cell having a layer of a nematic or long pitch cholesteric liquid crystal
material contained between two walls which carry electrode structures and surface
10 alignment treatments such as a rubbed polymer or grating structures. These alignment
treatments produce a strong alignment and surface tilt to the liquid crystal molecules.
The anchoring energy of such alignment and tilt may be reduced by including an
amount of a treatment which is either spread on the wall or added to the liquid crystal
material. The treatment may be an oligomer which may be produced by UV
15 polymerisation of material containing esters, thiols, and/or acrylate monomers.

Fig.1.

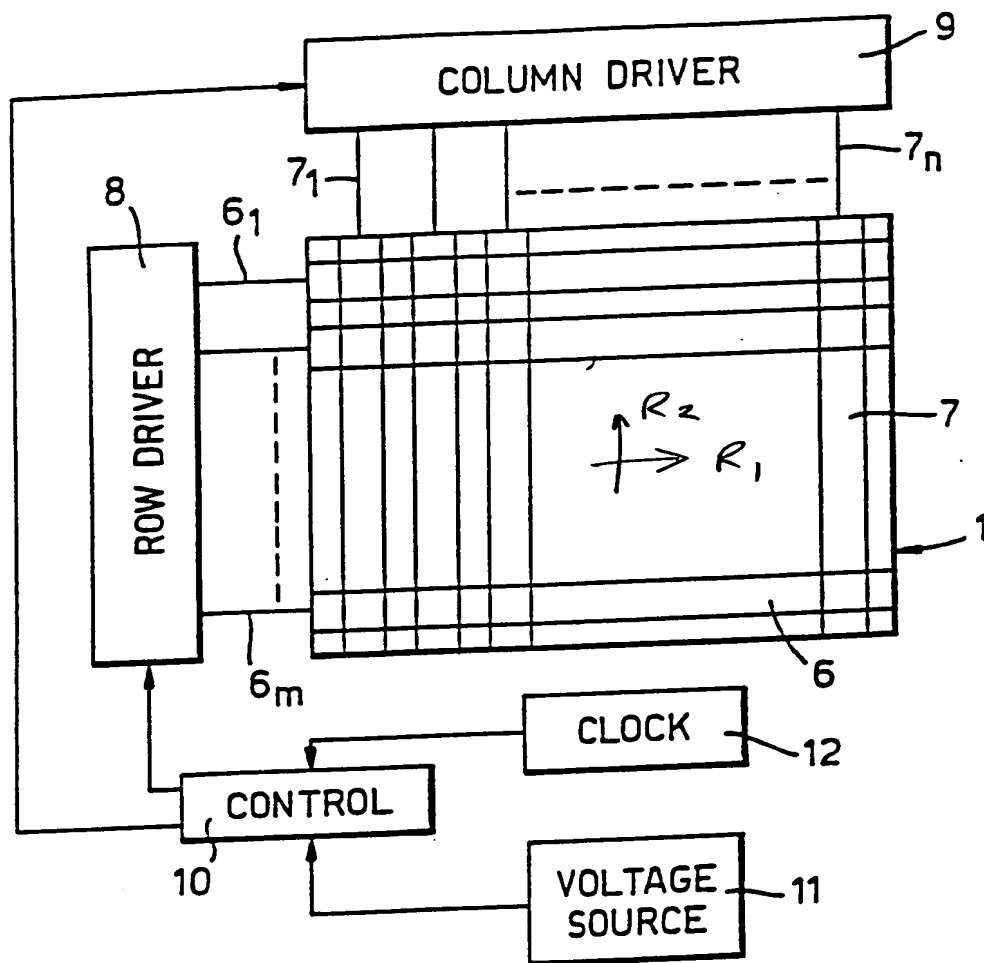
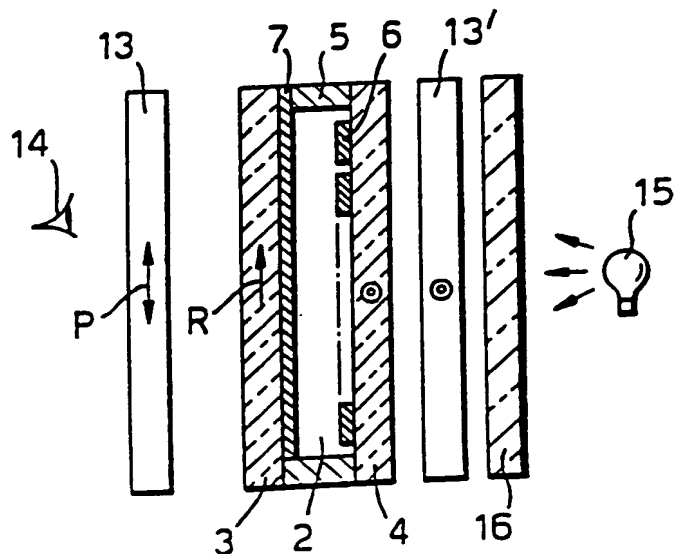


Fig.2.





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Figure 3

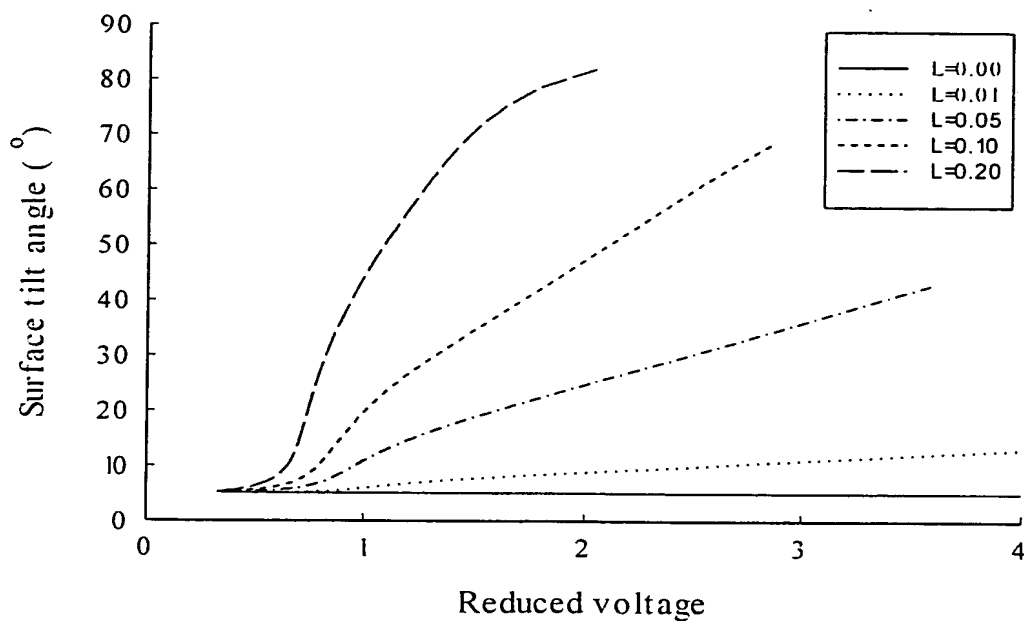


Figure 4

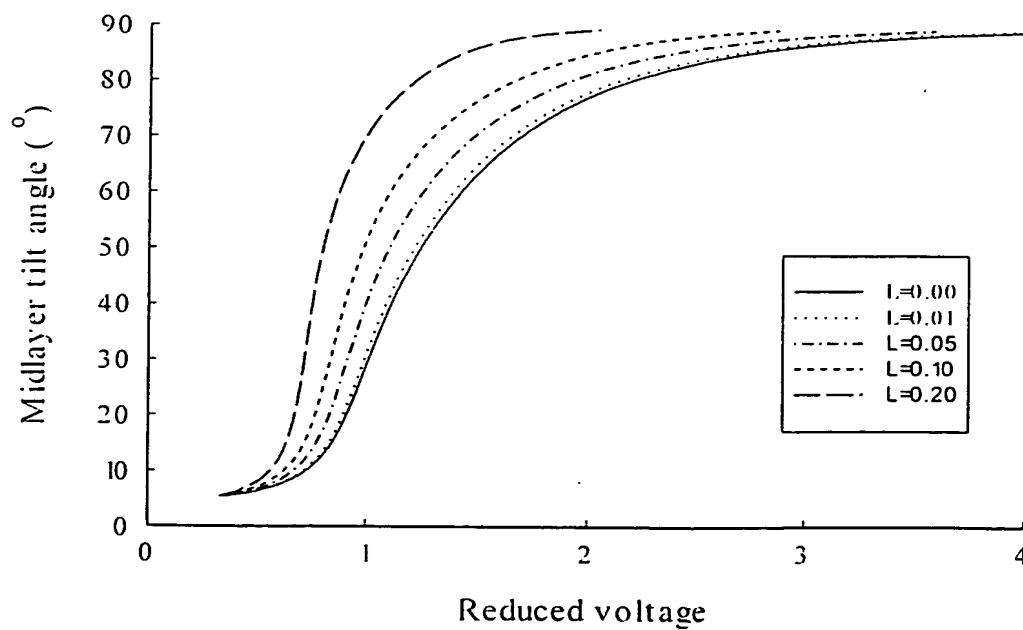




Figure 5

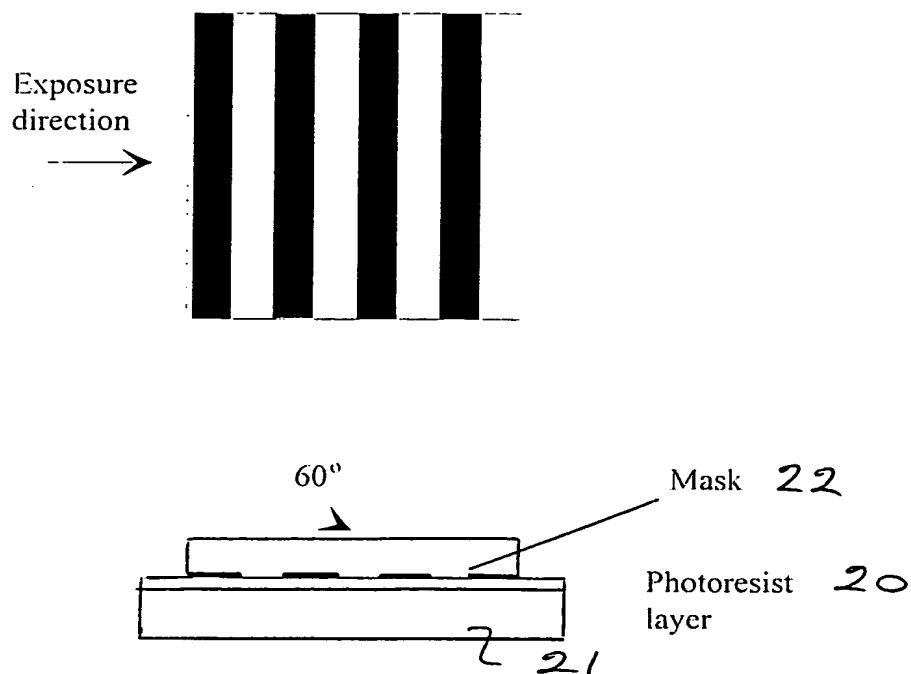


Figure 6

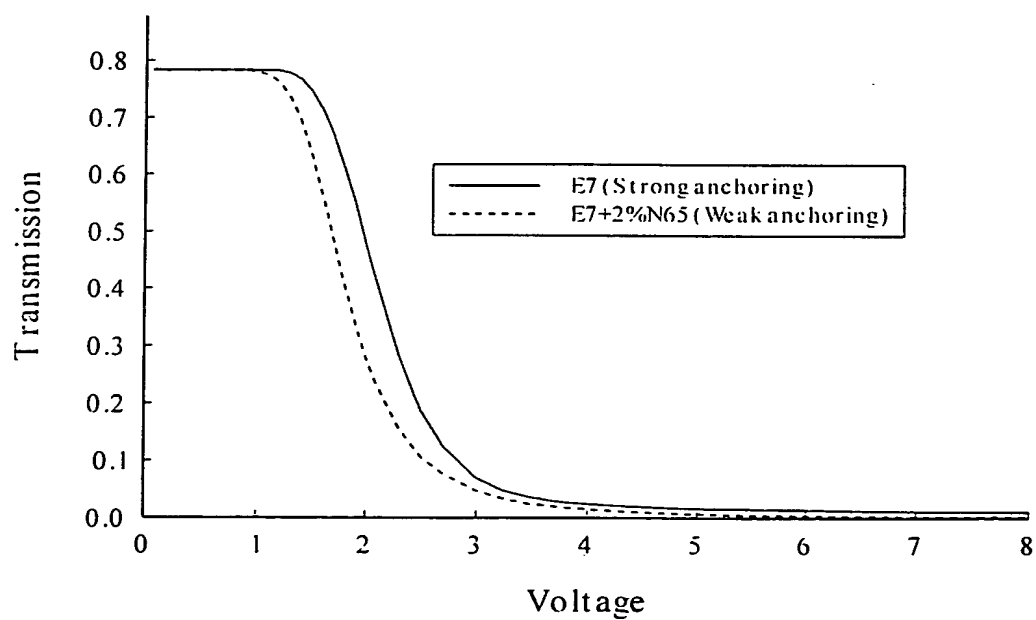




Figure 7

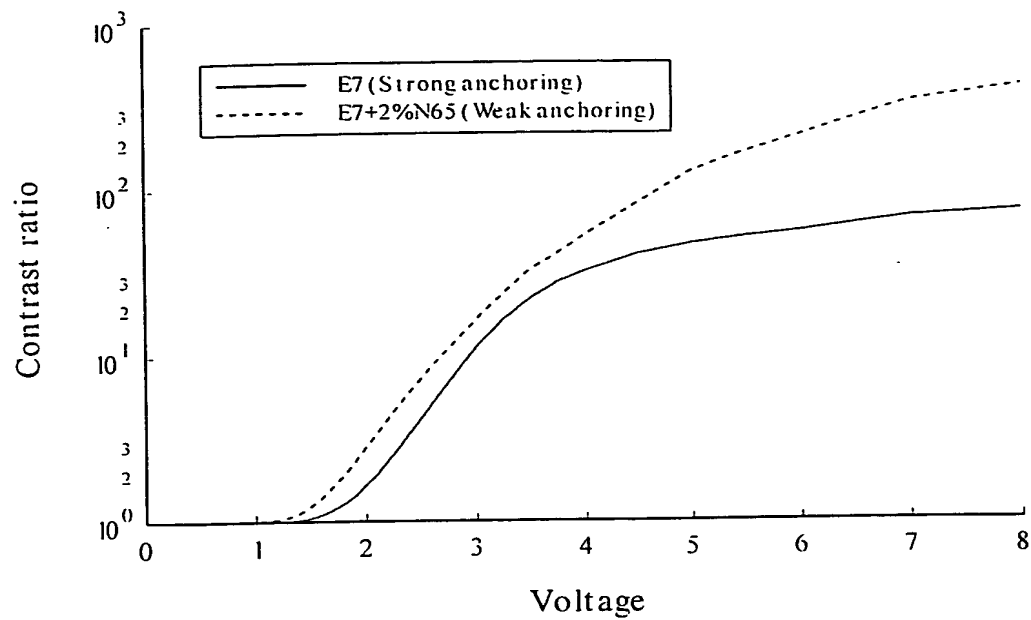
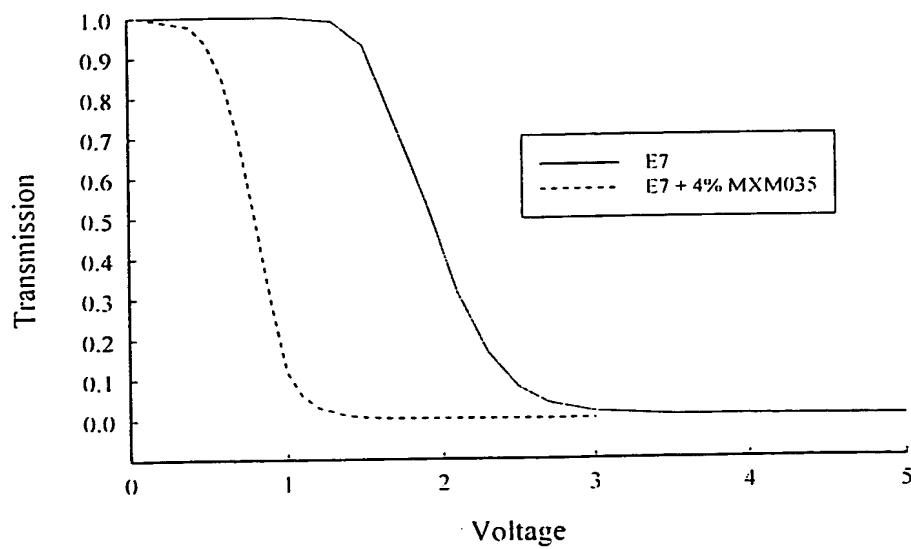


Figure 8





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Figure 9

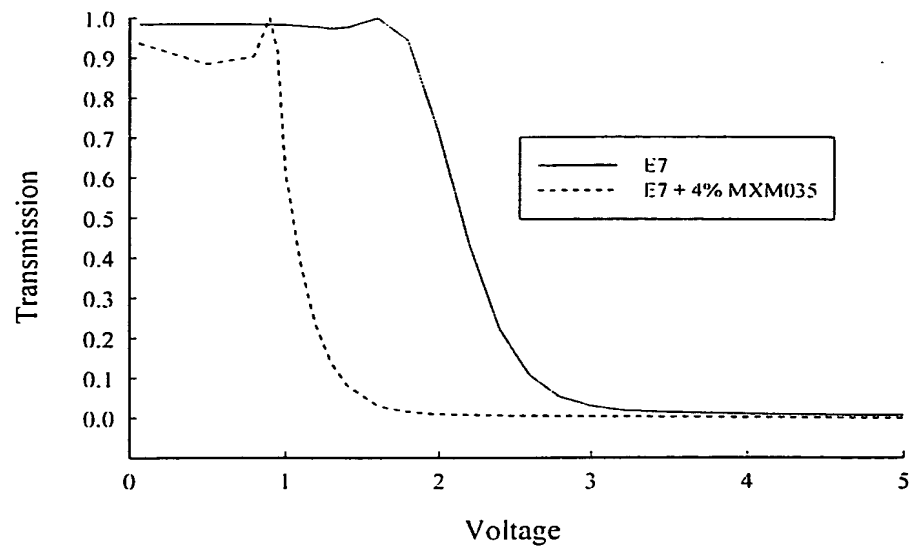
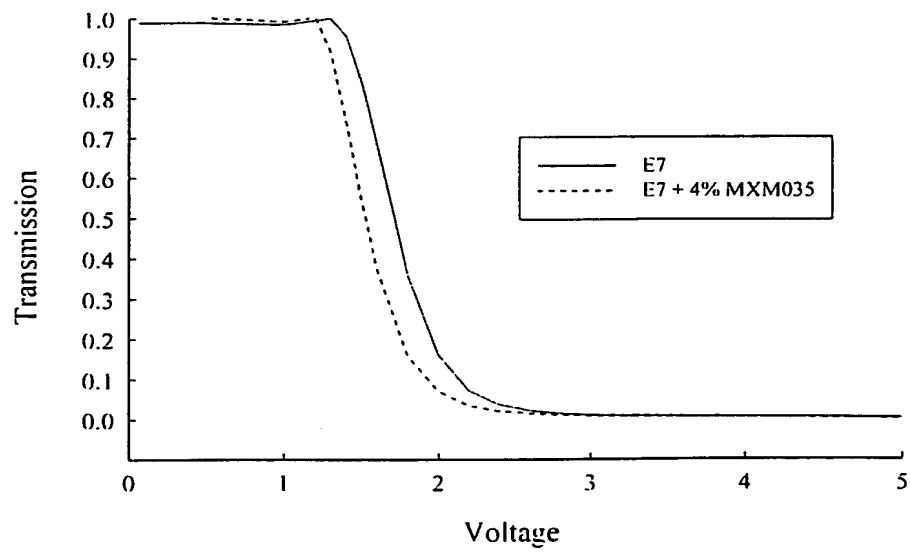


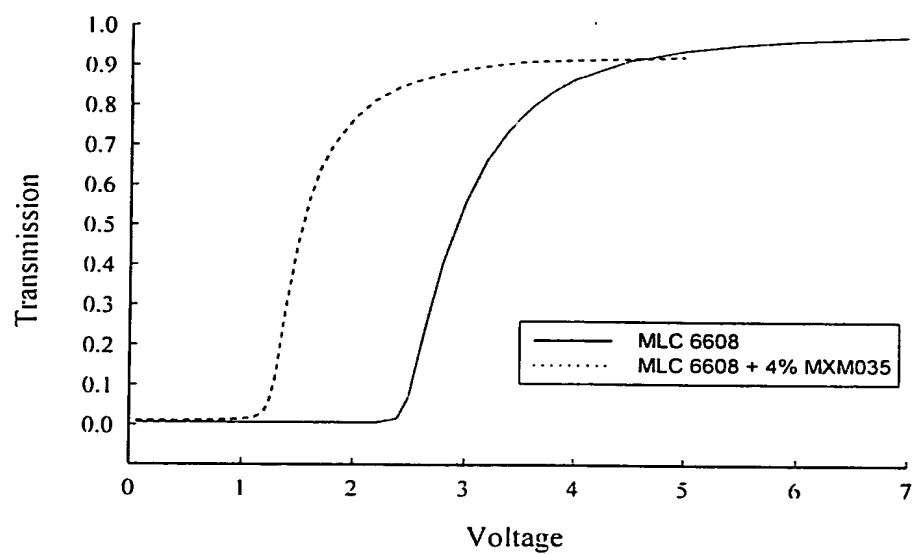
Figure 10





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Figure 11



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